RISK ASSESSMENT OF RENEWABLE ENERGIES: GLOBAL EXPOSURE

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ABSTRACT
The current stage of renewable energy (RE) development poses new challenges to this sector. The existing mechanisms of state stimulation of Renewable energy system are gradually exhausting its capacity. This requires the development of new methods to support the industry, or giving them up altogether. This article presents the results of the theoretical analysis of the systemic features of RE risk assessment at each stage of a project's life cycle. A sectoral approach to the risk assessment of energy projects is proposed. It is based on the well-known logit-model that studies a set of external and internal indicators. Based on this model, a study of the dynamics of the risk indicators of RE projects on three basic stages was conducted. Calculations were made for RE projects implemented in different countries of the world, including China, USA, Canada, Japan, India and a number of European countries. Initially, all projects were divided into three main groups depending on the types of state support: concessional lending, subsidies or the lack thereof. Based on the results of the calculations, the overall and average dynamics of risk by group and by project stage allowed for assessing the global effectiveness of state measures to support the sector, as well as for drawing appropriate conclusions in the context of individual countries. The results of the study are of practical importance and will be used in developing a new approach to risk assessment, taking into account the specifics of the RE market, as well as in enhancing the concept of competition in the global energy market.
Keywords: energy, investment project, logit-model, project' stages, renewable energy, renewable energy sources, risk, risks' distribution, state support.

1 INTRODUCTION

Renewable energy (RE) is an example of an 'unconventional' sector in terms of project risk assessment. In particular, it is important to highlight the following main features [1]–[4]: standard financial risks have a minimal impact on the effectiveness of RE projects and sector companies [1], [4]; the most significant risks in the activities of the sector companies and projects are risks caused by a set of political factors (legislative, financial and other types of dependence of investors, instability of state support, etc.) [4]; a lot of instruments of state support for RE projects cause heterogeneous risks of various levels of impact; political risks, including those related to state support for the sector, are typical of RE projects throughout the life cycle; a relatively short life cycle of RE projects (2–3 years on average) complicates the task of more detailed and strategic risk assessment of the sector projects; relatively recent development of the RE market prevents the accumulation of sufficient statistical information for the use of exclusively deterministic methods of risk assessment for projects; to improve a project's efficiency, risk assessment in RE should be connected to at least three main stages of the life cycle.

Together, the above features of risk assessment in RE projects and the current need for state support of this sector give rise to a complex and urgent task of conducting theoretical and applied research of efficiency and reasonability of state stimulation measures for RE projects in the context of the assessment of specific sector risks. This study examined RE projects implemented not only in the leading countries of the sector (China, US, EU countries), but also in other regions (India, Canada, Russia, etc.) [5]–[10].

The result of the study is the theoretical systematization of the main features of the evaluation of RE projects, including the various stage by stage steps, while taking into account the specific

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features of each one of them. This article presents a practical assessment of the effectiveness of state support measures for RE on the basis of the risk-oriented logit-model. The results of the calculations were used for comprehensive comparative assessment of the reasonability of two methods of state support and non-provision thereof. It includes the exclusion of RE projects that did not initially require any state support from a risk perspective. The obtained results are of practical importance and will be used in the development of a fundamentally new risk-based approach to the evaluation of RE projects at each stage. In the future, this will enable the development of the author's concept of competition in the global energy market [11].

2 PECULIARITIES OF RISKS ASSESSMENT FOR RE PROJECTS

The risk assessment of RE projects should be connected to the stages of the project life cycle. The short duration of RE projects requires that the study only evaluate three main stages of the project: pre-investment, investment and post-investment. In general, they are characterized by the following features:

1. Each stage has its specific features content-wise, which determine a specific approach to risk assessment.
2. The combination of risks at each stage can be strictly distinct, and each risk has its own individual level of influence and probability.
3. Risk assessment is stage-specific, depending on the period and related forecasts.
4. Stage-specific risks are studied over time. This study makes possible to assess how effective risk management programs are at each stage of the RE project.

The specific characteristics of risk assessment at each stage of RE projects are presented in Table 1.

Table 1: Peculiarities of risks assessment in renewable energy projects: current status.

		Features of risks assessment		
Stage	**Short characteristic**	**Initial information for assessment**	**Methods for risks assessment**	**Evaluation of political risk**
Pre-investment	Project planning, organization of financing	Only forecast information on the project, including risks, and the market state (data of the business plan); availability of information on the implementation of RE projects with similar characteristics	Preferential use of qualitative (expert) methods of risk assessment	High uncertainty about the possibility of state support, existence of associated risks

Investment	Construction and commissioning of the RE facility	Actual data on the RES project, the market state; clarification of the calculations on the level of risk before the stage (project reports, contracts)	The combination of qualitative and quantitative methods, the priority of mathematical models in the accumulation of data on current and similar RE projects	High probability of instability/ cancelation of state support, the existing of associated risks
Post-investment	The operation of the RE facility	Accurate project data before commissioning of the RE facility	It is possible to use only quantitative tools with sufficient information on the implementation of the RE project	Reducing the impact of political risks

The comparison of risk indicators for adjacent stages makes it possible to evaluate the efficiency of the risk forecasting and management system in RE project. The calculated risk *at the pre-investment stage* is a forecast one for the investment stage; *at the investment stage* is a potential one for the post-investment stage of the project.

Integration of the specified features in a single mathematical model will make it possible to estimate quantitatively an individual level of risk at each stage of the RE project. From the methodological perspective, the solution of this problem will be the basis for the quantitative assessment of the political risk, which has a significant importance for RE, and indicate the expediency of state support for the project at each stage.

3 METHODOLOGICAL APPROACH TO RISK ASSESSMENT OF RE PROJECTS

The study of the level of risk in renewable energy system (RES) projects is based on a globally recognized approach: assessment of the forecast *logit*-model in eqn (1) [12]–[14]:

$$PD = \frac{1}{1+e^{Y}}, \tag{1}$$

where PD is Probability of Default of RES project; e = 2,71,828; indicator Y is an integral indicator estimated by the proposed model.

The calculation of the probability of a default of projects is based on the model (2), taking into account the specific characteristics of the country's economy, local and international energy market [14]:

$$Y = -a_0 - a_1 \cdot K_1 - a_2 \cdot K_2 - a_3 \cdot K_3 - a_4 \cdot K_4 - a_5 \cdot K_5 - a_6 \cdot K_6 - a_7$$

$$K_7 - a_8 \cdot K_8 - a_9 \cdot K_9 - a_{10} \cdot K_{10} - a_{11} \cdot K_{11}, \tag{2}$$

where $a_0, a_1, \ldots, a_{11}$ are the indust-specific constants of significance of the coefficients for the fuel and energy sector.

The qualitative assessment of energy projects is provided by the *dummy*-variables K_1, K_2, K_7, namely: K_1 takes into account the factor of 'age' of the energy company, K_2 is the characteristics of the credit history of the energy company-project initiator, K_7 reflects the regional affiliation of the project. They take values according to the conditions (3):

$$K_1 = \begin{cases} 0, & \textit{if the company was created} \\ & \textit{more than } 10 \textit{ years ago} \\ 1, & \textit{if the company was created} \\ & \textit{less than } 10 \textit{ years ago} \end{cases} \qquad K_2 = \begin{cases} 0, & \textit{if company has} \\ & \textit{positive credit history} \\ 1, & \textit{if company has} \\ & \textit{negative credit history} \end{cases}$$

$$K_7 = \begin{cases} 0, & \textit{if company is located in the capital} \\ 1, & \textit{if company is not located in the capital} \end{cases} \tag{3}$$

The quantitative assessment of the risk level is based on the calculation of other exogenous and endogenous financial and economic indicators: K_3 is the current ratio of the project; K_4 the ratio of profit before tax and interest paid in the project for the period; K_6 the weighted average key interest rate of the Central Bank; K_8 the return on assets; K_9 the return on equity; K_{10} the growth rate of the project equity capital and K_{11} the growth rate of assets of the project for the period.

$$K_5 = \ln\left(\sum_{\beta=1}^{m} EC_\beta\right), \tag{4}$$

where K_5 is the weighted average capital of the company; EC_β the equity capital of the energy company for the β period.

Taking into account the specific features of the fuel and energy sector, the distribution of industry-specific constants is presented in Table 2.

The proposed model assumes the following total values (5):

$$\text{PD} = \begin{cases} [0;0.2) & -\textit{minimal risk of project} \\ [0.2;0.4) & -\textit{low risk} \\ [0.4;0.6) & -\textit{average risk} \\ [0.6;0.8) & -\textit{high risk} \\ [0.8;1] & -\textit{maximum risk} \end{cases} . \tag{5}$$

Table 2: Value of the constant coefficients of the model for the fuel and energy sector.

Indicators	a_0	a_1	a_2	a_3	a_4	a_5
Value	3,07,371	37,033	89,734	−86,711	−70,110	−16,427
Indicators	a_6	a_7	a_8	a_9	a_{10}	a_{11}
Value	−0.1399	−0.6913	−50,894	−1,53,882	73,667	−2,20,294

4 PRACTICAL ASSESSMENT OF RISKS IN RE PROJECTS

An assessment of the risks distribution by stage was carried out for 28 selected RE projects in different countries. It includes countries such as China, USA (market leaders [5], [6]), a number of European countries, as well as India, Japan, Russia and others. The subjects of the study are projects that lie within the popular top-priority areas of RE development: solar, wind, hydro, geothermal and bioenergy.

All projects are divided into three groups according to the methods of direct state support: concessional lending (10 projects, 35.7%), subsidies (7 projects, 25%) and the absence of state support (11 projects, 39.3%).

An important feature of RE projects is their relatively short life cycle (about 2 to 3 years). Therefore, within the framework of this study, it is assumed that the pre-investment stage lasts only the first 6 months, the post-investment stage for the last 6 months and the investment stage throughout the entire duration of the project.

4.1 Distribution of risks in the case of concessional government lending of RE projects

Table 3 shows the results of risk calculations for the RE projects that received concessional government lending.

The results indicate a rather low efficiency of the mechanism of concessional government lending: in three RE projects the risk level increased to the maximum value; in projects where the risk was at the maximum initially, the same dynamics remain [15], [16]. In a number of RE projects with a minimal risk at the pre-investment stage, this indicator also remains at the same level. However, such projects initially did not require state support as a tool of reducing risk.

To study the overall dynamics of the risk, the average value of the indicator at each of the three stages is calculated (last line of Table 3 and Fig. 1). Thus, the level of risk increases from stage to stage, reaching the average value to the post-investment stage.

4.2 Distribution of risks in the case of subsidizing of RE projects

Table 4 presents the distribution of the risk level by stages in the case of non-repayable subsidies for RE projects.

The study of the subsided RE projects did not reveal any dependencies on the stages. In this case, RE projects demonstrate a stable maximum or minimal risk value, an increase of risk to the maximum level or a decrease to the minimal to the post-investment stage. Therefore, there is not the sustainable positive influence of the mechanism of subsidies on the efficiency of RE projects [16], [17].

The mean value of risk for such projects varies insignificantly within 0.015 in the zone of average risk (last line of Table 4 and Fig. 1).

4.3 Distribution of risks in the case of the absence of state support for RE projects

The results of risk distribution in case of the absence of direct state support are presented in Table 5.

Almost half of the described RE projects show a stable minimal risk level. Such projects initially do not require any government incentives. Less than a third of the reviewed projects are characterized by the maximum level of risk (in one case – an increase to the maximum value). The remaining RE projects are able to either reduce the level of risk, including to the minimum value, or remain within these limits.

Table 3: Distribution of risks: government lending.

RES types	Project	Initiator	Period	Stage	Duration	Risk (avg.)	Risk profile
Solar power	Solar generation facility in the Mojave desert, USA	Government of USA, Abengoa SA	2016–2017	Pre-investment	2016	0.478	Average
				Investment	2016–2017	0.739	High
				Post-investment	From 2017	1	Maximum
	Solar generation facility in India (100 mW)	Azure Power Global Ltd, Solar Energy Corporation of India, Canadian Solar	2015–2016	Pre-investment	2015	1	Maximum
				Investment	2015–2016	1	Maximum
				Post-investment	From 2016	1	Maximum
	Solar generation facility in Australia (5 mW)	Canadian Solar Inc.	2015–2016	Pre-investment	2015	0	Minimal
				Investment	2015–2016	0	Minimal
				Post-investment	From 2016	0	Minimal
	Solar generation facility in India (648 mW)	Adani Group	2015–2016	Pre-investment	2015	0	Minimal
				Investment	2015–2016	0	Minimal
				Post-investment	From 2016	0	Minimal
	Solar generation facility in Japan (1.3 mW)	SoftBank Energy	2015–2016	Pre-investment	2015	0	Minimal
				Investment	2015–2016	0	Minimal
				Post-investment	From 2016	0	Minimal
	SPP Staromaryevskaya	Private company LTD 'Solar Systems'	2014–2018	Pre-investment	2014	0	Minimal
				Investment	2014–2018	0.599	Average
				Post-investment	From 2018	1	Maximum
Hydropower	Hydropower facility in Canada (40.6 mW)	Innergex Renewable Energy Inc Pref	2015–2016	Pre-investment	2015	0.945	Maximum
				Investment	2015–2016	0.941	Maximum
				Post-investment	From 2016	0.936	Maximum

	Hydropower plant (HPP) in Columbia (400 mW)	Enel Green Power, Emgesa	2014–2015	Pre-investment	2014	0	Minimal
				Investment	2014–2015	0.115	Minimal
				Post-investment	From 2015	0.229	Low
	Dam and HPP in Canada	Acciona	2015–2024	Pre-investment	2015	0	Minimal
				Investment	2015–2024 (avg. 2015–2018)	0	Minimal
				Post-investment	From 2024	No data to calculate	
Wind power	Wind generation facility in Greece (10.8 mW)	Terna energy	2015–2016	Pre-investment	2015	0.237	Low
				Investment	2015–2016	0.127	Minimal
				Post-investment	From 2016	0.016	Minimal
	Average values of risk			Pre-investment		0.266	Low
				Investment		0.352	Low
				Post-investment		0.465	High

Table 4: Distribution of risks: subsidies.

RES types	Project	Initiator	Period	Stage	Duration	Risk (avg.)	Risk profile
Solar power	Solar power plant (SPP) in Germany	7C Solarparken AG, Siemens, Government of Bavaria	2016–2017	Pre-investment	2016	0	Minimal
				Investment	2016–2017	0	Minimal
				Post-investment	From 2017	0	Minimal
	Solar generation facility in Canada (5.64 mW)	UGE Ltd	2014–2016	Pre-investment	2014	1	Maximum
				Investment	2014–2016	1	Maximum
				Post-investment	From 2016	1	Maximum

	Photovoltaic SPP in China (100 mW)	Panda Green Energy	2016–2017	Pre-investment	2016	0.891	Maximum
				Investment	2016–2017	0.944	Maximum
				Post-investment	From 2017	0.997	Maximum
	SPP in China (10 mW)	Zhonghuan Photovoltaic System Co.	2014–2015	Pre-investment	2014	0	Minimal
				Investment	2014–2015	0	Minimal
				Post-investment	From 2015	0	Minimal
	Solar generation facility in Canada (51 mW)	Canadian Solar	2014–2016	Pre-investment	2014	0	Minimal
				Investment	2014–2016	0	Minimal
				Post-investment	From 2016	0	Minimal
Wind power	Wind generation facility in Sweden (23 mW)	Eolus Vind AB	2015-2016	Pre-investment	2015	0	Minimal
				Investment	2015–2016	0.5	Average
				Post-investment	From 2016	1	Maximum
	Wind-diesel complex at oil field (Tatarstan)	Private company LTD 'Aktiviti'	2013–2014	Pre-investment	2013	1	Maximum
				Investment	2013–2014	0.5	Average
				Post-investment	From 2014	0	Minimal
	Average values of risk			Pre-investment		0.413	Average
				Investment		0.420	Average
				Post-investment		0.428	Average

Table 5: Distribution of risks: absence of state support.

RES types	Project	Initiator	Period	Stage	Duration	Risk (avg.)	Risk profile
Solar power	Solar generation facility in Alamida district, USA	NextEra Energy, Google, GE	2014–2015	Pre-investment	2014	0	Minimal
				Investment	2014–2015	0	Minimal
				Post-investment	From 2015	0	Minimal

	Photovoltaic power plant in El Salvador (101 mW)	NEOEN, Del Sur, Inter-American Investment Corporation	2015–2017	Pre-investment	2015	1	Maximum
				Investment	2015–2017	0.994	Maximum
				Post-investment	From 2017	0.987	Maximum
	SPP in North Carolina, USA (32.1 mW)	Phoenix Solar AG, Duke Energy	2012–2015	Pre-investment	2012	0	Minimal
				Investment	2012–2015	0.111	Minimal
				Post-investment	From 2015	0.222	Low
	Solar generation facility in New-York, USA (15.3 mW)	UGE Ltd	2016–2017	Pre-investment	2016	1	Maximum
				Investment	2016–2017	0.5	Average
				Post-investment	From 2017	0	Minimal
	Solar thermal PP (280 MW), Arizona, USA	Government of Arizona	2010–2016	Pre-investment	2010	0	Minimal
				Investment	2010–2016	0.5	Average
				Post-investment	From 2016	1	Maximum
Wind power	Wind generation facility in North sea (312 mW)	Dong Energy, PNE Wind	2014–2015	Pre-investment	2014	0	Minimal
				Investment	2014–2015	0	Minimal
				Post-investment	From 2015	0	Minimal
	Coastal wind power plant (WPP) in North sea, Belgium (165 mW)	Sumitomo Corporation, Parkwind NV, Mee-wind	2015–2017	Pre-investment	2015	0	Minimal
				Investment	2015–2017	0	Minimal
				Post-investment	From 2017	0	Minimal
Geothermal power	Geothermal power plant (GPP) in Philippines (20 mW)	PetroGreen Energy, TranAsia Oil & Energy Development, PNOC Renewables Corp.	2014	Pre-investment	2014	0.994	Maximum
				Investment	2014	0.994	Maximum
				Post-investment	From 2014	0.994	Maximum

Biopower	Conversion of CHP to a biomass plant, Denmark	Dong Energy, AffaldVarme Aarhus	2016–2017	Pre-investment	2016	0	Minimal
				Investment	2016–2017	0	Minimal
				Post-investment	From 2017	0	Minimal
Hydropower	Tidal marine power plant, UK (160 mW)	Atlantis Resources Ltd, Natiral Energy Wire	2016–2017	Pre-investment	2016	1	Maximum
				Investment	2016–2017	1	Maximum
				Post-investment	From 2017	1	Maximum
	HPP Boguchanskaya	Private company LTD 'Sibir Engineering'	2012–2015	Pre-investment	2012	0	Minimal
				Investment	2012–2015	0	Minimal
				Post-investment	From 2015	0	Minimal
Average values of risk				Pre-investment		0.363	Low
				Investment		0.373	Low
				Post-investment		0.382	Low

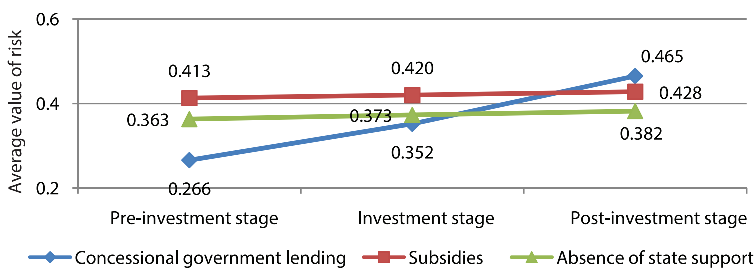

Figure 1: Distribution of the average level of risks in RE projects: by type of state support.

Table 6: Average risk in the case of exclusion of projects with zero risk.

Instruments of state support	**Average values of risk by project stages**					
	Pre-investment		**Investment**		**Post-investment**	
	Original sample	**Excluding 'zero-risk' projects**	**Original sample**	**Excluding 'zero-risk' projects**	**Original sample**	**Excluding 'zero-risk' projects**
Government lending	0.266	0.665	0.352	0.702	0.465	0.738
Subsidies	0.413	0.963	0.420	0.815	0.428	0.666

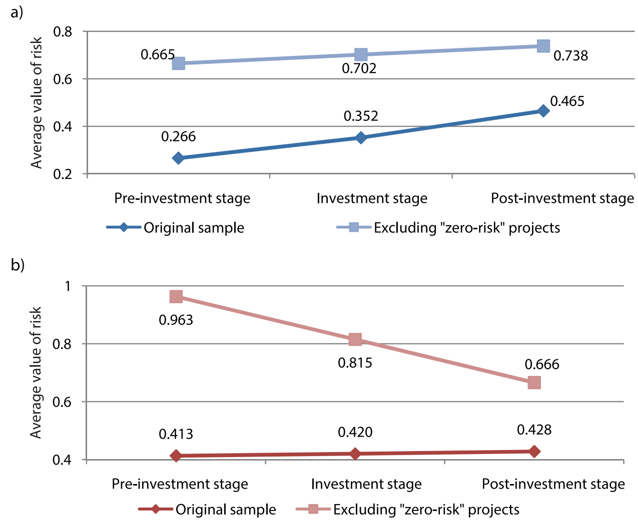

Figure 2: Comparison of average risk in the case of exclusion of projects with zero risk, by: (a) government lending, (b) subsidies.

The average risk in such RE projects (last line of Table 5 and Fig. 1) is consistently in the group of low risk.

One of the criteria for the ineffectiveness of state stimulation of the sector is the provision of support to those RE projects, which are initially characterized by a minimal value of risk. The author assumes that such projects do not need any incentives at stage one. For the subsequent assessment, the average risk values were calculated and a comparative analysis was performed for the cases of government lending and subsidies without taking into account the described RE projects (Table 6 and Fig. 2).

Calculations show that in the case of *concessional government lending*, the real level of risk almost doubles and ends up in the group of high risk. The exclusion of zero-risk projects from the group of subsidy recipients revealed an interesting dynamic. At the pre-investment stage, the average risk tends to the maximum, and by the end of the project is reduced to a high level. In practice, this means that, on the one hand, a tool of non-repayable subsidies can be effective for RE projects, which are characterized by initially significant level of risk. On the other hand, it provoked an increase of risk in risk-free projects at the pre-investment stage. However, in the case of subsidies, the average risk has also almost doubled.

5 CONCLUSIONS

A rapid pace of RE development has been achieved through active state support for this sector. However, the research presented in the article clarifies this view. Calculations showed that the most effective incentive tool is in fact the absence of state support mechanisms for the sector. In this case, there are no sharp changes in risk, and its average value is within the low level. Provision of subsidies for RE, in general, also shows a stable value of risk. However, in comparison with the absence of support, the level of risk increases to a medium value. The least effective tool was concessional government lending. When this mechanism was applied, risk at the pre-investment stage was the lowest (low risk group), and by the post-investment period it showed the highest possible value among all projects. Among the reasons for such results is the high impact of political and legislative risks [18]–[20].

The obtained results allow determining promising methodological directions for further research. They are associated with the development of new deterministic risk assessment tools for the main stages of the project, taking into account the specific character of RE. The new mechanism should help to answer a difficult question as to what tools of state support are best suitable for which projects, and which projects do not require additional incentives at all, taking into account the regional affiliation and size of RE facilities. [21]–[23]

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